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ABSTRACT

This study is grounded in a reform calculus movement funded by grants from the National Science Foundation to find ways to improve student learning in mathematics, specifically in calculus. The study examines reasons why faculty accept or reject reform calculus teaching techniques, and what they consider to be the challenges and outcomes of these techniques. Interviews were conducted with four mathematics faculty at each of three Midwestern, Research 1 public institutions--a national research institution, a land grant university, and an urban university--who were involved in teaching or in the assessment of reform calculus, as well as with administrators, institutional researchers, and faculty development specialists. Interview questions covered such topics as whether students were ready for college calculus, students' classroom behaviors, new teaching strategies, what destinations lay ahead for calculus-trained students, how well students spoke the language of mathematics, changing faculty roles and practices, how involvement in reform had affected careers, and barriers to adopting new teaching techniques. The study found that faculty who were open to reform embraced the challenges and the payback realized by getting closer to students, noting, however, that these techniques required a greater investment in time. (Contains 23 references.) (CH)

Factors Influencing Faculty Motivation to Improve Teaching: Scenes from University Mathematics Departments

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Introduction

Many public criticisms have been made of undergraduate education, and in particular, of faculty teaching. These criticisms are especially strong against large public research institutions, and take several familiar threads. One is that the faculty do not care about students, and that students are left to face an impersonal institution without faculty support. Another is that faculty have no motivation to keep up their quality of teaching after receiving their final promotions, and as a result become "deadwood." These arguments can especially be heard in regard to the general education courses that students take early in their undergraduate studies, such as calculus. Such criticisms in the 1980s spurred the National Science Foundation to fund grants to faculty to try to find ways to improve student learning in mathematics, and specifically in calculus. What emerged, called in this paper reform calculus, is a change in approach to calculus that seeks to engage more students in the material while creating greater retention of calculus concepts.

In regard to the specific calculus curriculum, reform calculus emphasizes story problems in order to relate calculus to the real world (or a problem-centered curriculum). Writers such as Deborah Hughes-Hallett (who wrote one of the major reform calculus texts with funding from the National Science Foundation, a 1990 text often called the "Harvard text") ask faculty to become more of a facilitator of group projects and active learning. Faculty listen to students as they try to develop understanding, identify gaps in knowledge, and ways to clarify what they have just learned. Teaching becomes a human experience of relating to students not just communicating a body of knowledge. Small class size is necessary for the development of trust needed for students to engage in discussion and take risks in learning. Small class size also allows for detailed feedback on homework. Much of the beginning of these reforms started with faculty teaching growing numbers of students while reacting to an environment in which graphing calculators took away the teaching potential of formulas. Many of the faculty involved in this study, as well as nationally, became initially involved in innovations as a result of working on National Science

Foundation grants to address integration of new technologies into the calculus classroom. Initiatives have ranged from the total integration of calculators into the classroom to the creation of a new text focused on "real world" problems in which calculus is applied as concepts, rather than as abstract problems.

In our study, we found faculty who were excited about the growth in student learning, especially in those students who ordinarily would not be expected to succeed in calculus. We found plenty of issues that create challenges and dilemmas for faculty as well. The purpose of this study is to study the reasons that faculty accept or reject reform calculus teaching techniques, and to study what faculty determine to be the challenges and outcomes of these techniques.

Method

We elicited description and explanation of how innovative teaching strategies and assessment create greater student learning. In selecting institutions, we sought to ensure both a focus on teaching and a rich comparison between institutions. First, we identified campuses that had participated in the American Association for Higher Education (AAHE) Peer Review of Teaching Initiative, phase I. Noting both self-reported activity and literature highlighting innovative campuses, we reviewed the AAHE phase I participants to identify institutions that were also involved in mathematics reform. We selected three midwestern, Research I, public, North Central Association-accredited universities with similar undergraduate enrollments (23,000-24,000). To allow a broad view of teaching across institutional functions, we chose a land-grant university, an urban university, and a national research university. All three campuses reported high levels of innovative activity in teaching across disciplines.

National University is a flagship institution with approximately 23,000 undergraduate students and 13,000 graduate students. National University has selective admissions, although there is a strong emphasis on maintaining a high enrollment of in-state students. While this campus, like many Research I universities, receives public comment about a perceived focus on research at the expense of undergraduate tradition, it has a long tradition of a high level of research activity. National University has evolved into an institution of nineteen schools and colleges. National University still awards tenure in a traditional way (emphasizing research contributions rather than teaching), although this is shifting toward a more flexible tenure system that values teaching. National University is highly decentralized, and has few central mechanisms to encourage innovation; faculty at the departmental level have considerable influence over the way the curriculum is presented.

Landgrant University is a flagship institution in a plains state, with approximately 24,000 undergraduate students. Landgrant University recently eliminated open admissions, although the tradition of populism remains strong. The struggle between that tradition and a more recent push for rigor and research acclaim marks current campus debates. This is a campus on the move in a state climate of ambivalence toward its goals; while Landgrant University has recently earned its Research I designation, there are many who wonder if this research orientation is needed in this state. Each of Landgrant University's various colleges are chartered through the state legislature directly. Like National University, Landgrant still awards tenure in a traditional way (emphasizing research contributions rather than teaching), although this is shifting toward a more flexible system. Landgrant is in an interesting time in which many faculty activities in teaching innovation are matching with new administrative efforts to demonstrate commitment to undergraduate education.

Urban University is a large campus in an urban area, with approximately 24,000 undergraduates. Of its eighteen colleges, all but two are professional schools. This campus has many functions, ranging from providing the medical training in the state to providing a community college educational service to an area which is largely underserved in that regard. This campus functions at the highest levels of research while providing a broad outreach function to the community. The admissions standards are flexible to meet these wide ranging functions, and it attracts a largely commuter and adult working population as a result. Urban University in recent years has been a testbed for many innovations, as the

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administration has kept an eye on national trends and individuals who can help develop the institution in many areas. These strategies have allowed the university to better articulate successes to external communities (such as the state government and local industry and business) as well as better identify areas to improve (a daunting task on a campus with so many different areas of responsibility). Urban University has differing tenure criteria in many parts of the campus; while a faculty member can still choose a traditional tenure path, a faculty member may also choose paths based upon teaching or upon a "balanced case" of research and teaching. Much of the impetus for change in teaching comes from administrators, creating innovations at the central administrative level and recruiting faculty participants along the way, after the planning stage.

We interviewed four faculty at each campus who were involved in teaching or the assessment of reform calculus. Mathematics was selected based upon its interaction with students early in their undergraduate programs, its frequent responsibility for service courses that provide foundational skills for upper division major requirements, and the high profile of debate that reform calculus has had. We also interviewed administrators, institutional researchers, and faculty development specialists at each campus, to gain a richer understanding of teaching and learning practices from multiple perspectives. Finally, we also observed a number of meetings on each campus, including guest lectures, faculty meetings focusing on peer review, and program review meetings.

The process of our study resembles what Glaser and Strauss (1967) call "discovery of grounded theory." Moreover, a number of steps have been taken to strengthen the reliability and validity of our research approach. First, we apply Lin's (1997) advice for addressing reliability: we explain the steps taken and the rationale for identifying participants, document how we have entered each research setting, keep a record of our interview protocols, and spell out the steps taken in the analysis. Second, we follow Kirk and Miller's (1986) and Yin's (1994) suggestion by diversifying our methods of inquiry. We use both interviews and document analysis (campus newspapers, catalogs, and web sites) to increase the validity of our study. Third, we employ multiple and comparative case study designs and replication logic to strengthen validity (Lin, 1997; Yin, 1994). Replication of themes, categories, and methods across cases improves the generalizability of our findings.

Faculty and administrator interviews and field notes were coded by three researchers. We followed an iterative process of coding and discussion of categories, sharing insights into new themes as they emerged. Discrepancies among the researchers were discussed in terms of their meaning and relationship or links with other themes and were given careful consideration before returning to the texts or additional documentation for verification and decision. With-in case analysis and cross-case analysis proceeded according to the use of a variety of techniques suggested by Miles & Huberman (1984) including the use of matrices with key elements of context, structures, and processes. The cross-case comparison at the department level was useful in identifying similarities or common dimensions along which the cases could be analyzed including their distinct approaches to assessment, structures, innovations in teaching, and overall improvement of undergraduate education.

Theoretical frameworks

Several theoretical frameworks can address the ways in which faculty work to improve their teaching. Stark and Lattuca approach teaching by reviewing several influences upon faculty course planning, including content, context, and form (Stark & Lattuca, 1997). *Content* refers to faculty members' personal influences that inform teaching scholarship (such as background, view of academic fields, and self-perceived educational views). *Context* encompasses student and institutional considerations, including campus resources (such as support for instructional development or funding for assistance), knowledge of teaching and learning literature, student characteristics and goals, and a multitude of other external factors that may exist. *Form* refers to decisions faculty make in course planning, including goals, subject matter, and learning activities. Stark and Lattuca describe these arenas as sequential, but multidirectional; within their model, content, context, and form happen in order, but often revisit previous steps through feedback and course adjustment.

Stark and Lattuca's continual learning might be labeled by Senge as a *learning organization* (Senge, 1990). Such learning organizations involve several aspects: *Systems thinking*, "invisible fabrics of interrelated systems" tying together business and other group endeavors; *personal mastery,* a special level proficiency that a person achieves through commitment to lifelong learning in areas of the most personal interest; *mental models*, assumptions and stereotypes individuals carry that shape their world view; *building shared vision*, shared "pictures of the future" that revolve institutional work around common ideas, rather than the charisma of an individual; and *team learning*, in which individuals suspend assumptions and engage in free-flowing dialogue, seeking not only solutions but also interaction patterns that inhibit learning (pp. 7-10). Senge's areas take an interesting shape applied to the Stark and Lattuca model; relabeling the Stark and Lattuca model in Senge's language might create a model of systems thinking (faculty background and socialization), mental models (faculty views of their academic fields), shared vision (purposes of education faculty bring to the teaching environment), team learning (external feedback that faculty accept and incorporate into their teaching) and personal mastery (self-evaluation and course content revision that feeds back into the beginning of the model).

Boyer calls for reconstruction of faculty work to shift focus from a research-teaching-service orientation to a four branch construction of scholarship: discovery, integration, application, and teaching (Boyer, 1990). *Discovery* refers to most basic elements of the current research branch: revealing new knowledge and creating paths of inquiry. *Integration*, an element of both current research and service branches, challenges faculty to place discoveries in a larger interdisciplinary fabric of knowledge: to communicate findings, critique others' findings, and weave together multiple researchers' findings into a coherent whole. *Application*, similar to other types of service, involves faculty in the larger academic and external communities, not only finding ways to use new knowledge, but also discovering new items for their research agendas.

In constructing the scholarship of *teaching*, Boyer not only includes the essential classroom component, but also faculty peer review of teaching as well as research and writing about pedagogical aspects of one's discipline. With teaching scholarship's multiple manifestations, Boyer advocates multiple evaluation techniques, including portfolios, written evaluations by alumni, peer evaluations, and other methods appropriate to specific disciplines. Boyer criticizes the current use of research as a sole or dominating criteria for tenure and promotion decisions. The teaching scholarship perspective complements both Stark and Lattuca's individual perspective and Senge's organizational perspective; such scholarship involves building a shared vision promoting teaching, involving others (team learning) to provide feedback to one's own teaching, as well as promoting personal mastery and growth. These are not competing models, but rather, complementary frameworks. Faculty members resistant to innovation or teaching improvement will no more contribute to effective learning organizations than they will meaningfully improve specific courses over time. As student needs or faculty opportunities shift, learning organization cycles can benefit innovative faculty members.

With those frameworks in mind, we can reflect upon how faculty in our study have changed their thinking regarding their teaching, and what byproducts have resulted for both students and faculty.

Reflection from the perspective of calculus faculty

There can be a perception that students are very different on different types of campuses: That students at more selective universities bring a level of seriousness, maturity, motivation and intellect to their studies that students at open admissions universities do not. Many faculty we interviewed shared in this belief, often believing that the task of educating students in calculus was markedly different depending on admissions selectivity. I highlight National University and Urban University (the extremes of admissions selectivity in our study) to demonstrate the remarkable similarities between these campuses, and likely between these campuses and most math departments.

Student preparation: Are students ready for college calculus?

One area in which, at first blush, the campuses differ is in the area of student preparation, taking the cases at the extremes in terms of the types of students they attract. It would seem that the National University students will enter calculus quite ready (if not overprepared) for the task, while Urban University students will, for the most part, come into a calculus class with rusty skills and a wide variety of levels of readiness in the classroom. It is true at Urban University that the faculty are frustrated with varying levels of student preparedness. As one professor noted:

> This is where you get resistance from faculty. That because high school failed, so now the university comes to pick up the job of the high school and then you call that improvement in post-secondary education. I really believe that the teaching of those students who are well-prepared sure, it could be improved, but that's not where the hard problem is. The real hard problem is how do you deal with this huge number of students coming in who are unprepared? . . . . For some (faculty) it's a burden and for some people it is a mission. (Former department chair, Urban University.)

Many of Urban University 's students are of non-traditional age, and may have been prepared for calculus many years before (rather than recently). However, the students at National University often arrive with calculus on their transcript but fading from memory quickly. In contrast to the Urban University faculty complaints about secondary education, National University faculty comment that students often think they know calculus because they have course credit, but in reality did not retain the concepts. As one calculus instructor notes:

> (The advanced placement course) has come to be something which it was not designed to be; it's now being used as a way to get into (National University). You take this course, you write it down on your application form, you never planned on taking any exams or taking any credit for it. So, here are students, all of whom believe that they had an A in this material. And in fact, many of them don't even test into calculus because their basic skills are so weak. (Instructor, National University.)

National University faculty additionally complain that there is no ready measure in the admission portfolio for calculus readiness; as they put it, "the SAT fails to measure calculus preparation." On both campuses, faculty suggest that high school preparation is not focused on getting people ready for college calculus. Although an argument can be made that the students on these campuses differ in preparation, the result is the same: Faculty confront sections of students with varying preparation levels struggling to grasp the concepts.

Student motivation: Do students want to do anything while in class?

The admissions standards of the institution and even the previous courses listed on a transcript do not necessarily guarantee preparedness for calculus. Similarly, these indicators do not guarantee a difference in motivation to become extremely involved in the material, either.

The students at National University are largely a group of traditional-aged, residential students with bright prospects. Many plan to apply to graduate or professional programs after finishing their undergraduate work. The students at Urban University are a more diverse group in age, course taking behavior, and previous high school and employment experiences, ranging from traditional aged full time students to part time students who have worked full time for many years, most of whom plan to stay in the area upon graduation (whether they choose to go to graduate school or to get a better job). In spite of this apparent difference in aspiration, both groups have many students who bring a "punch the ticket" attitude toward calculus courses; they are not interested in the concepts, but are interested in meeting the requirement for the next course in the line. This "punch the ticket" attitude results in considerable initial student resistance to reform calculus methods such as group work (which takes considerable student time), as well as resistance to simply taking the time individually to review textbook readings. The sentiments from their respective faculties sound quite similar:

> I think it's the expectation which we being a "feel-good society" have imparted on students that, go to the college, you sit there, okay? You don't have to read the books, you don't have to do anything, and the whole purpose is you pay your tuition. In the end, you get a piece of paper. Education as credential. (Former department chair, Urban University.)

> Many of the students we have now are here to go to Business School or Medical School – or at least they say they are – and what they want of the faculty is that we stay out of their way. They weren't planning on learning anything. (Instructor, National University.)

Interestingly, in both cases, the people who enter courses seemingly less disposed to learn calculus succeed better with the reform calculus concepts. At Urban University, in courses where group work or written assignments are used, the students who do best are older women (who have better verbal skills) and the students who hate the exercise most are 18 year old males (most of whom have done well in previous mathematics courses). At National University, similarly, students who have learning styles that do not depend on memorization succeed more with reform calculus concepts than those who have had previous success, since the old formula for success is no longer useful to meet the goals of the reformed course. In both cases, although all students have equal footing (since students of all learning styles have gaps to fill in learning reform calculus), this equal footing feels like losing to those who have previously been successful in mathematics. As one Urban University professor noted:

> What was interesting from the study that we did was that the best discussions in finding these multiple assumptions (about how to attack a calculus problem) that each of the different answers came from groups where I had older females in the group. Returning female students do very well because it's a very verbal skill, and they're thinking about the problem, and the people that were annoyed the most about this type of activities were my 18 year old males. It's a math class, just give me the formula, give me 100 problems of work, I'll execute it over and over and over again and that's how they want to do math. (Assistant Professor, Urban University.)

As noted, often the element of calculus in these courses that students are least prepared for is the demand placed on them to communicate about mathematics with other students and the faculty in ways other than simply applying formulas.

Destination: What lies ahead for students?

At all campuses, the destination of calculus-trained students is a source of challenge, since few calculus students will actually become mathematics majors. All of these departments noted growing enrollments as a result of an dramatically expanded number of majors requiring calculus for entry. Mathematics has become a training ground for employees in a variety of fields ranging from scientific fields to social sciences and professional schools. At National University, faculty started thinking more about what math majors were getting out of the courses, and surveyed ten years of alumni to ask what a math major had provided to them. Similarly at Urban University, faculty have been speaking with local employers to discover what they desire in a prepared college graduate. Both departments are concerned with the destination of their students, and the preparation their students have when they reach that future job or course. Although people in most cases take math because they have to, not because they want to, faculty want to help students develop the ability to apply mathematical reasoning to other disciplines and situations. One of the National University faculty demonstrates the tensions of the multiple destinations of calculus students:

> So for example, we have quite a large number of social science students in calculus. And fewer than half of our first semester students in calculus are engineering, so there is the question of what are the goals of the program. The traditional math program is really largely to develop people who are willing to do graduate work in mathematics and there's a nice congruence between what we were teaching and their progress towards graduate work in mathematics or a high mathematical area. When it didn't go all that way, then one could question a number of the syllabus items in the first year program. (Professor, National University.)

New teaching strategies

The hallmark of the reform calculus movement is a shift from a "plug and chug" method of rote problem solving for mastery of technique to a group oriented discussion and presentation method of conceptual learning. The reasons for this are multifold. First, many faculty were horrified to find that, when asking students what the purpose of some of the concepts was, students often confused the formulas with the concepts; the students believed the formulas were the reason for calculus, rather than calculus being the origin of formulas. Second, with the technological advances of graphing calculators, faculty faced both an instructional dilemma and an opportunity in creating problems that were less tidy and more "real world" oriented, challenging students to apply concepts in a time when the calculator could handle the formula portion of "plug and chug" tasks. Finally, the increasing requirement of calculus preparation by many majors, enrollments and syllabus lengths were ballooning, and steps needed to be taken to better engage the students and make learning goals more reasonable.

Several elements mark reform calculus as practiced by Landgrant and National Universities (and in lesser degrees by Urban University). These elements include sharing in the creation of new materials among faculty, developing student writing and speaking skills in mathematics, increasing student time on mathematics tasks, and discussing more openly what comprises good teaching as a faculty.

As mentioned in the introductory section, the most commonly accepted textbook which arose from various NSF grants was one written by Deborah Hughes-Hallett of Harvard University. However, this text alone does not provide enough material to keep student groups working. Many faculty noted that they spent considerable time creating new projects for students, since projects created for traditional calculus courses were no longer useful for students in reform calculus classes. New projects are designed to be applications of calculus concepts to real world situations, in which numbers might be messy and more than one right answer might emerge. As well, new projects are designed to be sufficiently complicated so that one person alone cannot solve the problem, requiring that the student team work together toward solutions. Additionally, new projects are designed to take advantage of technologies available (ranging from the use of graphing calculators to email group discussion, to use of special software to create notebooks of student projects). Preparing such new materials absorbs time, and as a result has encouraged collaborative faculty work in trading materials and expanding the repertoire of projects available to give to students. As one Landgrant professor noted:

> Well, we need more things ready to go. . . . You design what you think is a really neat project and no one can even understand the first paragraph, much less answer the project and you get this feedback that says I don't understand what the heck you're talking about, this project was a waste of my time, and that means it was a waste of your time designing it. (Undergraduate Education Coordinator, Landgrant University.)

The new projects in development are meant to emphasize concepts, rather than technique. Within reform calculus sections, technical items are removed unless they are necessary to understand the concepts or to succeed in future coursework. What technical items are necessary has been a source of debate at all three campuses studied. While reform calculus teaches concepts, there are faculty in other departments that care more that students have traditional formulas, so that debate shapes some of what happens in the calculus classroom. In reform calculus classrooms, mastery of concepts is the number one goal, so when necessary, some repetition is used in the classroom to help with retention of material. United with this in class repetition of material, group projects are designed to lead students away from "plug and chug" formula work to communication about mathematics. The variety of approaches and learning styles available in a student group reinforces the calculus concepts by having different interpretations and methods of explaining the concepts in action. Many of our faculty noted this as a benefit to all students:

> Well, they do seem to enjoy the variety. Also because of the variety there's a greater chance that students can find a successful way to express their knowledge on the subject. (Undergraduate Education Coordinator, Landgrant University.)

In the face of these shifting classroom goals and activities, faculty have more openly discussed what good teaching is. In large part, much of the teaching discussion has arisen from the efforts to teach others how to operate reform calculus sections. At National University, for example, there is a well defined outline of the course that is now used to help new instructors teach with these new methods and know what to expect from their classes. This outline defines to the minute what activities to do and how to expect students to react. The emphasis on teaching faculty to operate in this environment has helped connect many of the short term faculty, reducing their feelings of isolation. Many of these short term faculty have since moved on to positions at other institutions, and have continued to teach calculus using reform techniques, spreading the practice to a variety of departments.

Many faculty who are not enthusiastic about reform calculus and similar innovations believe that teaching is about giving a flawless presentation. To these faculty (who, for the most part, were the successful students in their own mathematics classes), the more perfect the presentation, the better the learning will be. Not only are traditional lecture techniques less time consuming to administer, but they encounter less engagement and less resistance from students, and therefore feel more natural. As some of our more innovative faculty note: "Well it takes a great deal of energy to change the way you teach so yeah, there's a lot of resistance." (Undergraduate Education Coordinator, Landgrant University.) However, those faculty who do get involved in reform calculus tend to develop more curiosity about students over time. At all institutions, although reform calculus faculty may disagree with this view, they do respect the opinions of faculty with these beliefs. However, many faculty involved in reform calculus note that when they started listening to students after faculty completed what they considered to be good classroom presentations, faculty we interviewed realized students were not grasping many concepts. Faculty might derive this new knowledge from listening to students discuss these items in groups (either listening to the groups or reading their email conversations), or from grading student work throughout the semester (instead of delegating that work to others). Directly reviewing student work in this way is another new teaching technique, since faculty have immediate feedback to use in adjusting presentations and reinforcing concepts.

Unease about using these new teaching techniques extends to many calculus instructors (who, for the most part, were the successful students in their own mathematics classes). Not only are traditional lecture techniques less time consuming to administer, but they encounter less engagement and less resistance from students. However, those faculty who do get involved in reform calculus tend to develop more curiosity about students over time, in spite of the frustrations. As a National University instructor noted:

> They had the satisfaction of getting close to students. Of seeing the student genuine understanding and talents develop and there's an enormous downside. It's much harder. It's substantially more time. It demands all sorts of interpersonal skills. It's not infrequent for instructors to say wait a minute, I'm not a psychiatrist here. What am I

> doing listening to whether or not this person can get along with that person in the (residence hall). I don't want to hear about it. I have no expertise in this field. (Instructor, National University.)

The switch to the reform calculus teaching styles was swift in two of the three departments we studied. In National's case, this quick shift was done outside of formal faculty decision making channels, allowing adaptation without the opportunity for faculty to obstruct the process through formal measures. As one faculty member noted: "We had the entire innovation before anybody in the department knew what was happening." In Landgrant's case, this swiftness of adaptation was due to a faculty consensus that group work techniques and other elements listed here could not be phased into traditional classrooms gracefully, but rather had to be adopted as a package. In both of these departments, the institutional and departmental emphasis on teaching has been and is growing, and adaptation of teaching innovations such as reform calculus was a natural match to other activities in the institution.

While Landgrant and National Universities have adopted all aspects of reform calculus, Urban University has chosen just to adopt the Hughes-Hallett text across the department. Some instructors use some of the reform calculus methods, such as group work and student mathematical journals (in which students demonstrate to instructors how they are approaching calculus concepts). However, the text was largely selected to "spice up" the range of examples with real world applications. On this campus, more mathematical innovative efforts have been poured into a "mathematics across the curriculum" initiative, in which interdisciplinary courses are created between mathematics and areas such as art, history, and biology, to demonstrate the role and impact of mathematical concepts in each of these areas. Faculty report at Urban University that this "spicing up" of the curriculum with the new text has not enticed students to spend more time reading the text, and do not seem to embrace the idea that the text was meant to be one of a set of strategies, and not by itself a cure for student motivation issues.

"Speaking the language of mathematics"

One of the more fascinating approaches noted through this research is the conception of mathematics as a culture. Several of these faculty referred to "speaking the language of mathematics," or simply "speaking the mathematics." The approach might be compared to that of a foreign language course, in which the foreign language is spoken exclusively within the classroom, cultural nuances are described within the language, and students attain language and cultural skill from both reading about the structure of the language and speaking (or attempting to speak and hear) the language until they truly understand it. Calculus instructors have always been adept at giving the formulas (the structure of the language). Reform calculus seeks to make the concepts (the meaning of the language) preeminent.

Just as a foreign language classroom as described immerses students into the language, reform calculus uses group work to provide the immersion experience. Within the groups, an environment is created in which students have to pursue many activities and speak to each other at length about math concepts. This social element is essential, although it can take a life of its own that can often bewilder the faculty. As one noted:

> Group work is good. It has them speaking the language and it's hard not to learn something if you're trying to speak the language and explain aspects of it to other people in the group. Although, it's amazing sometimes one member will say something that's utterly nonsense and all the other ones will say yes, and seem to understand everything that's going on, so I don't know what's happening there, but just speaking the mathematics, in the past they didn't do that. I think maybe that might be one of the, probably the strongest things that we have going that the newer strategies that we're trying to use is simply that they're speaking the mathematics, having to use it that way, to verbalize it, and begin to own it. (Undergraduate Education Coordinator, Landgrant University.)

Both students and faculty often come to math feeling that it is an area that they can compartmentalize life from, and feel less vulnerable in traditional mathematics classrooms (although students may feel personally nervous about passing). The group work adds to the nervousness students face, since now their failures or lack of understanding will be exposed to an audience of their peers. As noted before, students who are traditionally strong in mathematics have as much, if not more, anxiety about group work, since group work slows the pace that they usually enjoy working alone, and they have a difficult time immersing in concepts once they have become adept at formulaic work. However, many faculty reported that students develop group work skills that they use in other settings, and that former students report that much of their group work skill has come from their calculus courses. Application and communication are "real world" problems that are essential for students to master:

> Oh, I think there are huge benefits. I think that the tendency to reflect on your work, the ability to describe it verbally and to write clearly the ability to read carefully for meaning, those things are crucial and they'll tell you all the time 'I came back and I really understand how to look at a graph when we had one in biology.' They know that they're learning from this. (Instructor, National University.)

The structure of the groups is interesting. Smaller groups are used to allow students greater interaction. This prevents individuals from becoming anonymous or uninvolved in the projects. Group homework must be designed to be more difficult than individual problems, or else groups will tear it apart and work individually, rather than as a unit. Faculty experience this as a struggle to create new course materials, as stated previously. The problems presented are "real world" applications which allow students to discuss the ways in which calculus is applied outside of the classroom. Technology is often used both to enhance the problems that students must solve, or to provide communications vehicles for students to work together or to present their group work to faculty or other classmates.

The resulting product of the student groups is often not simply a solution to the problem, but a presentation (written, spoken, or both) to the instructor or the class regarding the problem, what decisions the group made, and how the group solved the problem. Again, rather than rewarding the application of a formula, emphasis is placed on describing the relevant mathematical concepts to peers using prose, rather than simple numerical answers. Faculty noted that having students write in whole sentences gives a better window about understanding of mathematical concepts. This window is as important to faculty members sense of self development as well:

> I discovered a long time ago that I enjoyed talking about mathematics to other people, so this was a way of doing this and I think in that same sense I enjoy talking about

> mathematics with people and I want to be more effective at it, so when ideas or things come along I try and pick up on that, what works, what doesn't, and how can I be more effective, how can I be more engaging. (Chair, Landgrant University.)

Changing practices and changing roles

Probably one of the more notable and immediate effects of new teaching strategies in use is creating a variety of closer relationships, of closing the distance between students and faculty. This is particularly notable in mathematics, since many faculty interviewed reported that they or other faculty had selected mathematics as a career, in part, to not have the stress of "gray areas" as a part of their work. Students, likewise, are often described as not wanting to be connected to others, but rather to finish the transaction of a course and move on to the next.

The most direct change is the relationship between faculty and students. Math departments in all three of these institutions, as well as in many institutions across the country, have had large calculus sections, in which graders handle the oversight of homework (and at times exams) and the faculty instructing the sections potentially could have little contact with student work until they saw the final grades and student course evaluations. On all three of these campuses, some of this distance was eliminated. Often simply removing the graders revealed to faculty new insight into student work (and which concepts students were or were not grasping); and many faculty commented that this was the first time in their careers that they were aware that students were not grasping specific concepts early in the term:

> And most instructors are not close enough to their students to recognize that something is really fundamentally wrong with the learning. You can teach in the old way and notice that they can't do quizzes and tests and say well, maybe they didn't study hard enough or maybe ah, they're not good at...they have test anxiety or whatever. (Instructor, National University.)

Even the simple act of removing answer keys allowed faculty to more closely view student work and find areas of struggle. This closeness in all cases, even during frustrating moments for the instructor, created more concern and knowledge about what students were learning, and what classroom techniques might help students learn more. Some of our faculty took pride in just getting to know students' names, and were pleased later to be able to talk to former students when they returned for letters of recommendation about what they were doing with their math skills in their majors and careers.

While the faculty-student relationship was obviously made closer through these techniques, the relationships between students were also made closer. Students, who largely are not math majors, through their group work have learned (and struggled) through the difficulty of having many different learning styles present in their work. According to faculty we interviewed, in several instances students have found that they are not the only people struggling through specific concepts, and this has given them confidence to continue in pursuing their math courses. These students report to our faculty interviewees later that the group skills they learned through these new math teaching techniques have served them well in work places and in their majors.

As mentioned before, the application of more social methods of teaching to math classrooms has created stress for many who have not had a large social component to their work. However, many faculty have applied their math skills to the issue of learning how students learn. They develop their own student development theories as a way to "solve problems," to create an almost mathematical structure with what they are learning about students in order to make sense of this information. When these faculty discovered that other people write about student development theories, this created a whole new area in which to be a student, or as one faculty member described it, being "a student along with my students." Not only have students been moved from a "plug and chug" approach to coursework, but now faculty also are learning new concepts during their courses and not applying a formula to problems. Many reported that they have moved from "expert" status to a more egalitarian "learner" status:

> So I'm a student along with my students. And sometimes students will just point out wonderful things I never thought of. Just this past I put a flow chart up on the board, it was kind of biffed up in some respects and we kind of straightened it out. After class, one of my students came up, and he said "You know, I really wouldn't do it that way. This doubling factor that you're using, explain to me why." He had a different strategy in mind, and you know, he's right. So the next time I wrote it up, I mentioned it, that

> he suggested this. So I'm with the students, and we kind of move forward together. (Professor, Landgrant University.)

Rejuvenating careers as a result of involvement in reform

One unintended consequence of the reform calculus movement has been a rejuvenation of many of the careers of faculty we interviewed. Most of our interviewees were fully promoted professors who had no future career hurdles as a result. This freedom from formal hurdles gave many of the faculty the confidence to try new strategies and to immerse themselves in their teaching. In most cases, this was an addition to their work, and not a replacement for research. Many faculty expressed that this is a time in their careers that they feel the luxury to experiment in areas they want:

> I have the luxury of being confident now in what I'm doing. I was explicitly before thinking I had to go out and impress people, but I'm old enough and experienced enough that I don't think I have to prove anything, that I can do things because I'm really interested in them not because I feel like it's part of my job where I have to, it's kind of a revitalizing experience to realize you can now really follow exactly what you're interested in. (Professor, Landgrant University.)

These faculty have many reasons for wanting to invest more time and effort into teaching, which coincide with their various research passions. Most truly love mathematics, and want to share their love for mathematics with others through their teaching. Many were attracted to the mathematical field by a curiosity and an enjoyment of solving puzzles and problems, and see their attempts to learn about student development theory and teaching as another way to invest that energy. Many feel simple pleasure in trying new teaching techniques. Many have found new intellectual areas to compliment their previous work (especially in the combination of new technologies with previous mathematical theories). An overwhelming number noted the intrinsic benefit of seeing students with different learning strategies and backgrounds having access to calculus knowledge, and potentially to future mathematics or science classes. One Landgrant professor noted that he is not sure that all of the effort will pay off, but he feels motivated to try:

> I'm putting together everything I do for this course on a web page, in one integrated thing, and I've got it organized in a way that I hope will be useful in the future.

> Whether or not it is another question, but at least I'm trying that and so making everything I do available to the students. My lecture notes, the whole smear, is available. So, that's sort of teaching with technology in a sense that I make everything open and available. (Chair, Landgrant University)

This attitude was both explicit and implicit in many of these faculty. Even our least innovative faculty noted that they feel compelled and excited by working with students who were exerting significant effort to learn, no matter how unprepared students were initially to start taking calculus. There is a drive in all of these faculty to work with excited students.

Much of the career rejuvenation comes from discovering new ways to express mathematics to others. Just as students have a cultural immersion experience in learning mathematics in groups, faculty develop their own communication skills and find an audience of students who are developing their own language of mathematics. Many of our faculty noted that they have worked on their presentation styles to become engaging enough so that students will understand their work:

> I'm thinking about the communication of mathematics and I have been for a long time. If I say something I want people to understand why I'm enthusiastic about it. Why I think this is neat. Why I think it's cool. Why I think it's interesting, or whatever it may be. I just enjoy doing that sort of thing. (Chair, Landgrant University.)

Some faculty are networking with other science departments, which challenges their mathematics communication skills and raises their priority. All of our institutions have developed in some fashion campus wide efforts toward teaching more communication skills across disciplines, which challenges mathematics faculty to develop communications components in their own courses. Finally, many faculty who have been working at these reform efforts for a long time have noted that all the elements of teaching and mathematics are tied together, and single elements cannot be isolated. Teaching is not complete without excellent communications skills.

Realism: Barriers to adopting new teaching techniques

There are many resistances to calculus reform, and most of them revolve around control: control over time, over the classroom, over departmental opinion, and even over the learning that takes place in other departments. There is also substantial concern over the control one has over one's own department. This section will focus on three of these areas: Time, adaptation, and administrative influence.

Time

There is no escaping the fact that reform calculus takes considerably more instructor time than traditional lecture-based calculus. Although, perhaps, homework may be submitted in groups (lowering the number of assignments), the complexity of the work requires more time to grade. Teaching students to write about mathematics takes considerable time. Balancing the teaching of several different skills (problem solving, critical thinking) rather than simply expecting formula manipulation is difficult. As well, when there are still few previously written mathematics projects, faculty time is taken in creating course materials. This resistance is respected by innovative faculty:

> But I don't fault my colleagues who need to get other things done. They get a lot done and they do it by being very careful with their time, so if my students start doing better, and the innovative courses don't do better, then they'll come around as soon as we work out ways of getting it done efficiently. If they don't do that much better, then they won't come along and maybe that's the way it should be. (Undergraduate Education Coordinator, Landgrant University.)

Classroom management is a tricky issue with reform calculus, especially with its emphasis on group work. The social component makes the class easy to distinguish from a traditional lecture class, where no one knows anyone else. People want to communicate, and sometimes it takes more effort to keep the class moving. As well, group dynamics become a part of the instructor's life, and the instructor may often be mediating conflict, hearing about out-of-classroom events (such as what is happening between people in a residence hall), and dealing more directly with student fears and anxieties about mathematics. This is an interpersonal effort that is unfamiliar to many mathematics faculty, and is difficult to learn.

Departmental adoption

Faculty at all three campuses displayed some resistance to reform calculus. At National University and Landgrant University, some resistance was overcome when instructors felt the reward of getting close to students and watching their talents develop. According to faculty we interviewed, some senior faculty initially called the reform "calculus light." There is criticism from many math and science faculty that more writing and communications emphases will turn math into a humanities area (inferring a softer, less rigourous course). Some faculty feel strongly that lecturing is the right way to teach, and think that team homework allows some to coast on other students' coattails or that team homework slows down the strong students.

As a result of these types of criticisms, reform calculus proponents have worked in strategic ways to get innovative strategies adapted in the department. In both National and Landgrant's departments, reform calculus was never voted on by department in order to adopt it in spite of some faculty resistances. This was done because, as one National University faculty member put it, "If you try to get a vote of the whole faculty, you won't get anything." The proponents are very careful about the language and rhetoric used to describe these techniques, so as not to give ammunition to critics who may look at any symbol as a reason why reform calculus is "calculus light. The innovation at both campuses grew quickly, so that even some resistant faculty were teaching using reform calculus techniques, even though they weren't sold on it. With the large number of part time instructors and graduate student instructors at both campuses, training new instructors is a perennial issue, since many new instructors come in having only seen the lecture method (although even this is lessening, as more of these instructors have encountered reform calculus in their undergraduate work).

Departmental authority

At National University and Landgrant University, faculty feel leadership, that reform calculus is where the department is going and that faculty are taking it there. By contrast, at

Urban University, there is a greater feeling that other departments and administrators are wrestling for control over the mathematics department, and that as a result the department needs to spend its time building up a research reputation so that it has equal footing with departments at more prestigious institutions and more reputational capital at its own institution.

The mathematics faculty at Urban University largely feel that administrators, when speaking of teaching, do not know the issues at hand, and are unmotivated to fix the outside elements (such as admissions standards or high school preparation) that might create more success in the calculus classroom

> Frankly, most students aren't helped, okay? So, well meaning things because of political pressure are often done here at our university that our faculty will just simply say huh, okay, you win, but I won't do it. (Former department chair, Urban University.)

As a result, people who are innovative in mathematics teaching are looked upon with skepticism, or as one faculty member stated: "(Reformers) are getting a lot of backing because it's a political will for change, so they're getting a lot of backing from outside the math area." This feeling that innovative teaching comes as an attack from outside leads some faculty to mock those who, in their eyes, are too invested in "touchy feely" techniques to teach rigorously. Rigor, in fact, is one element that the Urban University mathematics faculty is adamant about maintaining and increasing. They (like other faculty) point out that mathematics is a conservative discipline, and as such faculty want proof that new teaching strategies will be effective in preparing students to perform well in subsequent courses before they change their own teaching. Leaders in initiatives tend to be regarded as zealots. As one faculty member stated, "You know, people who want to do innovative new things, quite often go overboard. So there is a real fine line to tread administratively."

Conclusion

For those faculty who have opened themselves to the new ideas presented by reform calculus, even if these faculty were initially resistant, they tended to embrace the challenge and the payback from getting closer to students, feeling that students were gaining more holistic mathematical computation and communication skills. These faculty felt that they themselves were learning new skills as mathematicians and teachers.

All of the faculty in our study, regardless of their use or acceptance of reform calculus, cared enormously about student learning. The difference in approach seemed often to be a difference in interpretation of both personal responsibility for learning and personal ability to change the quality of learning for students. One of the faculty interviewed noted that "Mathematics is a conservative discipline," and he was right. The shift in personal ownership of learning, as well as in the skills taught, is a stressful shift for many, and one that will not happen overnight for all, even in the departments most open to innovation.

These techniques do require an investment in time, which often is added to a busy schedule without other elements being dropped. However, teaching as an area of scholarship has been especially enriching for those faculty who are tenured and fully promoted. These faculty felt freer to invest time in new teaching strategies and in learning more about student development and instructional theories. Rather than finding "deadwood" at this level, we found excited faculty who were passionate about what for them often was a new branch of scholarship. This finding has applicability not just within mathematics, but also across all departments.

Writers have noted the tangible role that reward mechanisms play in shaping behavior, and in particular, how people shape behavior to match that of people controlling rewards (Bandura, Ross, & Ross, 1963). However, though rewards play a role in faculty motivation, they are not the sole motivators; much more motivates faculty. One difficulty in creating a direct relationship between rewards, punishments, and other incentives and teaching behaviors is that much of the assumptions of many organizational writings focus upon a hierarchical industrial model, rather than the loosely coupled hierarchical and professional systems found in colleges and universities (Staw, 1983; Weick, 1976). Much faculty effort is voluntary; faculty are largely a motivated group of individuals who have selected careers that provide less financial reward, often as a trade to instead be part of a flexible community in which they are free to explore and discuss ideas and to have more professional autonomy.

Erikson proposes the idea of "generativity" as a motivator of older adults as they view their lives and consider their legacy to future generations of adults (Levinson, 1978; Walker & Quinn, 1996). The passing of skills and knowledge to new generations (whether between faculty and student, or between older and younger faculty) certainly influences the decision to assume faculty positions and the desire to teach when those positions are attained (Baldwin & Blackburn, 1981). Some of the older faculty we interviewed would concur:

> Well, one kind of – the most tangible benefit is you feel better about what you're doing in the classroom. You feel like you're working on it, you hope that your students are having a better experience as we know a little bit dicey to put down that they in fact are performing better because it's hard to make the comparison. I would hope that a lot of the students are performing better, having a more enjoyable time. I know that I feel better about my teaching and feel proud of some of the stuff that I'm doing. (Professor, Landgrant University, 371-375)

Faculty such as this individual have the advantage of a long career upon which to reflect and compare teaching experiences from one era to another. In this way, they can see their own improvement, and not only feel good about student learning, but about their own learning. Career perks other than money or job security attract faculty to their positions. Indeed, faculty satisfaction with their careers is often linked to the number of intrinsic motivators and rewards available (Clark, 1987). Autonomy and freedom are important aspects; having self-determination over much (if not most) of one's work week is considered essential to the decision to become faculty by many (Walker & Quinn, 1996). However, this autonomy differs according to how many of one's tasks are devoted to research and how many are devoted to teaching; the rewards accrued earlier in the career may also determine the relative autonomy of a faculty member (Bieber, Lawrence & Blackburn, 1992). Most of the more senior faculty we interviewed had enjoyed successful research careers, and looked upon reform calculus as a new source of inquiry.

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